BULLETIN 430 JANUARY, 1929

The Normal Multiple Sprouting of Seed Potatoes

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Wooster, Ohio

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THE NORMAL MULTIPLE SPROUTING OF SEED POTATOES

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INTRODUCTORY LITERATURE REVIEW

Morphologically the potato tuber is a storage stem, differing from an ordinary stem not only in the large amount of stored nutrients, but also in that each eye is a cluster of buds. Artschwager (6) and others have pointed out that there are at least three buds to an eye. On a tuber of the Russet Rural variety there are about 15 eyes, therefore at least 45 buds.

A very small proportion of the buds sprout when a tuber is planted under ordinary conditions. For a time after the end of the rest period the tubers are apically dominant. At this stage if a whole tuber is planted only one bud develops, usually the terminal; if the tubers are cut, characteristically but one bud develops on each piece (Appleman 2).

TABLE 1.—Number of Sprouts per Set* in Experimental Field Plantings

Summarized from the literature

Variety	State	Authority	Size of set	Sprouts per set
Irish Cobbler	Maine	Stuart *et al.* (16) 1924	2 oz.	3.8
Irish Cobbler	Virginia	Stuart *et al.* (16) 1924	2 oz.	2.5
Irish Cobbler	Missouri	Rosa (14) 1922	Not given	2.1
Early Ohio	N. Dakota	Werner (18) 1919	2 oz.	2.7
Early Ohio	Missouri	Rosa (14) 1922	Not given	1.6
Bliss Triumph	Missouri	Rosa (14) 1922	Not given	2.6
Rural New Yorker	Colorado	Clark (10) 1921	2 oz.	2.5
Rural New Yorker	Missouri	Rosa (14) 1922	Not given	2.3
Sir W. Raleigh	New York	Stewart (15) 1919	2 to 4 oz.	4 to 6
Carmen No. 3	Ohio	Ballou (7) 1910	2 eyes each	3.2
Russet Rural	Michigan	Moore (13) 1927	Not given	2.1
Burbank	Indiana	Arthur (5) 1892	40 grams	2.6 to 5.1
Russet Burbank	Idaho	Stuart *et al.* (16) 1924	2 oz.	2.9
Chas. Downing	Idaho	Stuart *et al.* (16) 1924	2 oz.	2.9
McCormick	Maryland	Appleman (3) 1924	3 oz. whole	6.9

*The term "set" includes both whole tubers and cut pieces used for propagation.

By the time plantings are made in the field apical bud dominance is weaker and two or more sprouts usually develop from each piece cut and planted in the customary manner. A number of investigators have counted the sprouts in experimental field plantings with results as summarized in Table 1. The average number of sprouts from seed pieces of ordinary size, as shown in this table, varied from 1.6 to 6. In no instance in the literature at hand is there a record of a field planting, from seed held over winter, that

produced consistently one sprout per seed piece. By the time of field planting, then, seed tubers are not completely apically dominant, but relatively few of the buds on each seed piece develop into sprouts.

Most studies of the number of sprouts have dealt primarily with the effect of the size of the seed piece. As early as 1892 Arthur (5) stated that the number of sprouts is a direct function of the weight of the piece, and that the weight is more important than the number of eyes. His general conclusion has been confirmed by other investigators.

It is also clear from the literature that factors other than size of the seed piece have an influence on the number of sprouts. For example, Stuart and his co-workers (16) found that 2-ounce sets from the same lot of Irish Cobblers produced an average of 2.5 sprouts per piece in Virginia and 3.8 in Maine. Rosa (14) planted 40-gram pieces of Early Ohio tubers three successive seasons in Missouri and found that the average number of sprouts varied from 1.9 in one planting to 5.2 in another (Table 2).

TABLE 2.—Variation in Number of Sprouts From Seed Pieces of the Same Weight

Early Ohio variety, cut pieces, 40 grams each, data of Rosa (14)

Year	Seed produced in	Sprouts per piece
1918	Northern state	1.9
	Missouri	2.7
1919	Northern state	2.5
	Missouri	5.2
1920	Northern state	2.0
	Missouri	3.1

Stuart and coworkers suggested that the difference between the character of sprouting in Virginia and in Maine might be related to the time of planting, or, to state it another way, to the length of storage. The longer the period of storage, the more numerous were the sprouts. This explanation may also account for some of the differences observed by Rosa. It may be noted in Table 2 that the Missouri-grown seed produced more sprouts than the northern seed. The Missouri seed was from spring crops that matured in midsummer, and the seed tubers were in storage longer than northern-grown tubers that probably matured in September. Prolonged storage appears to have resulted in an increase in the number of sprouts.

This interpretation is supported by observations of Appleman (3) who held tubers in cold storage, in one instance for six months and in another for a year, beyond the normal planting date and then obtained excessive multiple sprouting. Appleman also found that repeated removal of sprouts from whole tubers resulted in an increase in the average number of sprouts after each desprouting. Tubers weighing 6 ounces or less produced single sprouts in early April; in July, after 7 or 8 desproutings, there was an average of about 13 sprouts per tuber.

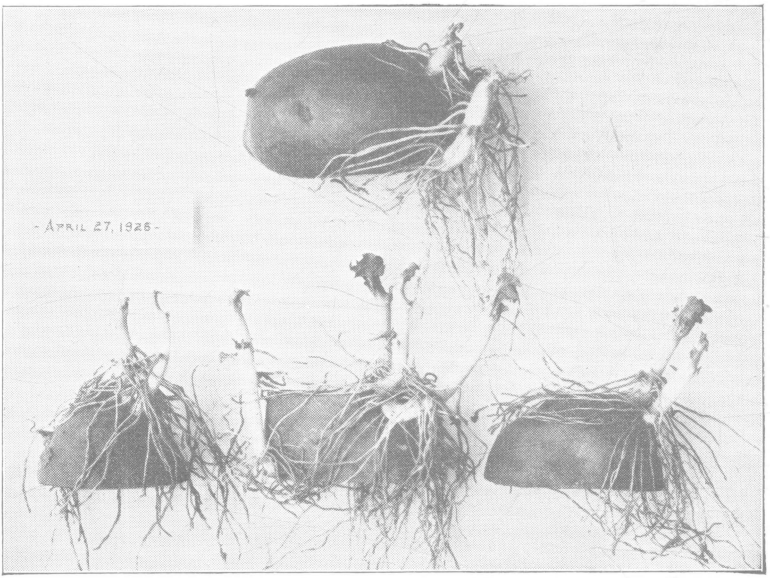


Fig. 1.—Typical multiple sprouting of the Russet Rural in April. Whole tuber above, cut pieces below

The writer's preliminary observations on the Russet Rural during 1924-25 further substantiated the view that the length of storage is an important factor in the character of sprouting. The resting stage of this variety extended to the middle of December: plantings during January, February, and March resulted in one sprout, then followed a gradual weakening of apical dominance as shown by a gradual increase in the number of sprouts in later plantings (Figs. 1 and 2). Neither the data in the literature nor these preliminary results were adequate, however, to serve as a basis for predicting the number of sprouts which would develop from a given weight seed piece planted at a given time.

The present work, therefore, aimed to be a comprehensive study of the factors affecting the number of sprouts developing from seed pieces of the Russet Rural variety. The Russet Rural was selected because it is the dominant variety of northern Ohio and because excellent certified seed was available. The study was chiefly concerned with conditions such as occur in commercial potato production, including date of planting, maturity of the seed, length of storage, storage temperature and ventilation, greening, and the soil temperature at the time of planting. Most of the experiments were repeated two or more seasons to establish, if possible, a basis for predicting the number of sprouts from seed pieces of ordinary size. The present report is restricted to these studies on sprouting habit, no attempt being made at this time to answer the practical question as to what number of sprouts will give the highest yield.

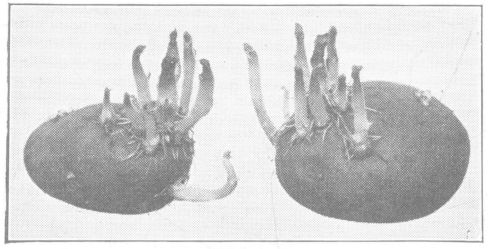


Fig. 2.—Typical multiple sprouting of small whole tubers in July

EXPERIMENTAL METHODS

For the studies of 1926 and 1927, certified Russet Rural seed potatoes were obtained each fall from northern Michigan. For certain phases of the work, such as the experiment dealing with the effect of maturity, the seed was grown at Wooster.

Except where noted, the seed tubers, immediately prior to planting, were cut into pieces weighing 56 grams (about 2 oz.). Because of the recognized importance of the weight of the piece on the number of sprouts, each piece was weighed when cut. A variation of 3 grams from the desired 56-gram weight was tolerated, but when cutting for field planting the total weight of a sample, usually 30 pieces, was not allowed to vary more than ten grams from the desired total weight.

Plantings in the greenhouse were in composted soil; plantings in the field were in Wooster silt loam.

The most serious source of error arose from partial rotting of the seed pieces after planting. When the soil was warm, particularly if it reached 25° C. (77° F.), rotting was almost certain, whether in the field or in the greenhouse. The same difficulty was encountered in the laboratory in an incubator at 25° C., whether

the sprouting medium was soil, sand, or sawdust. Rapid rotting gave the same effect as reducing the size of the seed piece; that is, a reduction in the number of sprouts.

A lesser difficulty was accidental injury to sprouts. Injury to a vigorous sprout stimulated the growth of two or more secondary sprouts with a consequent error when the sprouts were counted. Accidental injury, as would be expected, was more frequent in the field than in greenhouse plantings.

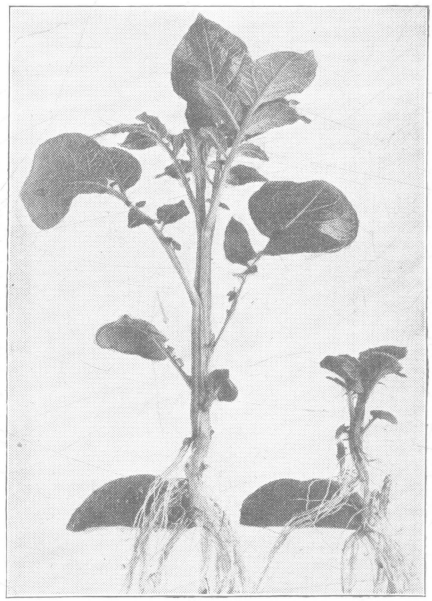
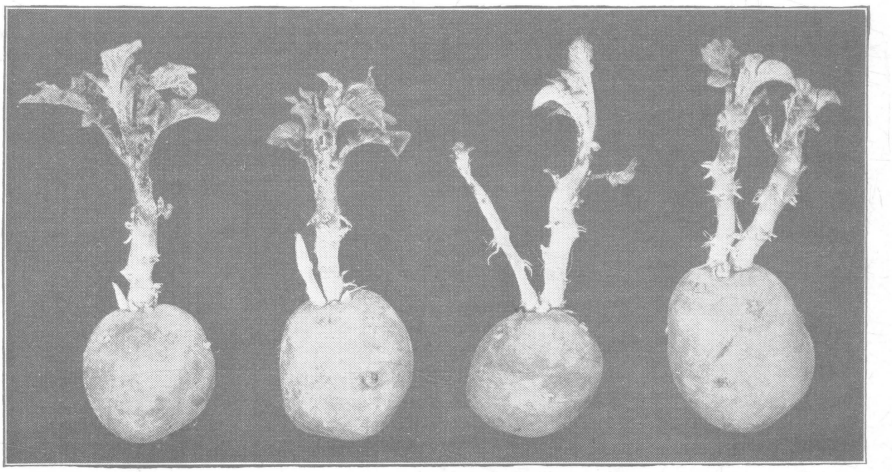


Fig. 3.—At left, normal one-sprout due to complete apical dominance. At right, the primary sprout being stunted because of its location at the extreme edge of the seed piece, secondary sprouts developed.

It was also noted that a sprout at the extreme edge of a cut piece failed to thrive. In a former study with the Early Ohio variety the writer (8) pointed out that apically dominant tubers cut longitudinally thru the terminal cluster of eyes occasionally developed several weak sprouts instead of the expected single sprout. This is illustrated here in Figure 3. If the terminal eye is located at the extreme edge of the seed piece its sprout apparently fails to obtain adequate nutriment and secondary buds start. To avoid this complication tubers were cut transversely rather than thru the terminal cluster of buds.

No method of cutting, however, entirely eliminated the development of weak sprouts. In normal multiple sprouting of whole tubers some of the sprouts were conspicuously more vigorous than others (Fig. 2) and the same condition held for cut pieces. In many instances in the present study weak sprouts were so small that in the field they were difficult to find and to count. When counting was deferred until harvest, some of the weak sprouts were dead and broken, and it was observed that those weak sprouts which remained green failed to produce tubers of marketable size. As it was impossible to count accurately the dead sprouts, it

seemed advisable to confine the attempts at accurate counts to the vigorous, tuber-bearing stalks. From a practical viewpoint the sturdy stalks only are of real significance, the weak secondaries being more in the nature of weeds. Occasional exceptions to this classification were necessary where the sprouts were so numerous that none produced marketable tubers. In such instances, all of the surviving stalks were counted.



A B C D

Fig. 4.—Types of sprouting in early April, illustrating the transition from a one-sprout to two-sprout stage

In greenhouse plantings, which were usually grown for only a few weeks, the count of sturdy sprouts comparable to that adopted for the field counts was based largely on personal judgment. Following the single-sprout stage, transition stages were found as illustrated in Figure 4. After observing the development of sprouts of varying degrees of vigor in the field, it was decided to include sprouts as large or larger than the weaker sprout of tuber C in Figure 4 as potentially tuber-bearing. Where the average count is given as one and a fraction it signifies that transition types were present, some counted as having one sturdy sprout, others as having two.

To simplify presentation, only the average number of sprouts per seed piece is reported in the following pages, with no indication of the individual variation within each experimental lot. Individual variation, however, increasing with the degree of multiple sprouting was characteristic of all plantings. The frequency dis-

tribution of three typical plantings is given in Table 3. The standard deviation rises rapidly as multiple sprouting increases but the coefficient of variability remains near 40. Similar frequency distributions are found in the data of Stuart *et al.* (16). Since the variation was characteristic of all plantings of multiple sprouting tubers it is deemed unnecessary to mention it further in this report.

TABLE 3.—Variation in Number of Sprouts From Individual Seed Pieces

Frequency distribution in plantings at monthly intervals. Cut pieces weighing 56 grams each

Date planted	Number of sprouts per piece							Mean number	Standard deviation	Coef. of variability
	1	2	3	4	5	6	7			
April 11	68	56	4	1	...	.....	.	1.52	0.598	39.6±1.9
May 11	27	48	45	21	8	1	.....	2.59	1.129	43.6±2.0
June 11	13	29	47	36	15	9	4	3.35	1.407	42.0±1.9

SPROUTING AT SUCCESSIVE PLANTING DATES

The preliminary observations disclosing a gradual increase in the number of sprouts in successive plantings were confirmed in 1926 and 1927.

TABLE 4.—Average Number of Sprouts From 56-gram Cut Pieces Planted at Different Dates

1924–25		1925–26		1926–27	
Planted	Sprouts	Planted	Sprouts	Planted	Sprouts
Dec. 1	0.00	Dec. 5	0.10	Dec. 11	0.00
Dec. 27	1.00	Jan. 12	1.00	Dec. 21	1.00
Mar. 16	1.00	Apr. 7	1.50	Mar. 1	1.00
Mar. 23	1.20	Apr. 20	1.71	Mar. 12	1.20
Mar. 30	1.50	May 10	2.00	Mar. 26	1.75†
Apr. 6	1.63	May 20	2.36	Apr. 11	1.52
Apr. 28	2.40	June 1	3.00	May 11	2.59
		June 11	3.47	June 11	3.35
		June 21	3.55*	July 11	4.50
		Aug. 4	6 00*		

*Counts not satisfactory owing to partial rotting of seed pieces.
†From a small planting in greenhouse, high count probably due to experimental error. Not included in graph.

The seed used in these experiments was stored thru the winter in a barn basement held as near 3° to 4° C. as feasible. In the spring when it became impossible to maintain the temperature below 5° C., the samples were moved to a cold storage operated at an average temperature near 3° C. This range of storage temperature has held seed in excellent condition; the yields following

such storage have been higher than from storage at a lower temperature (9). This was therefore considered to approximate ideal storage. Plantings prior to April 1 were in the greenhouse, those after that date in the field.

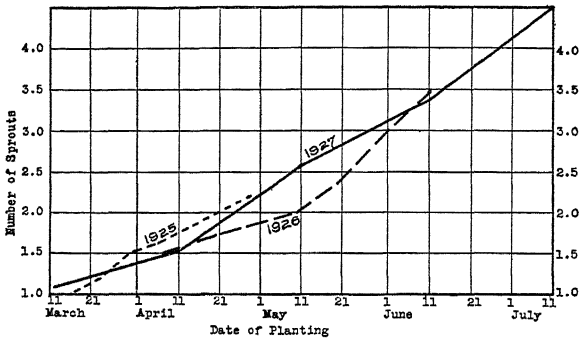


Fig. 5.—Illustrating the increase in multiple sprouting from seed pieces of the same weight planted at successive dates

Three seasons' data are given in Table 4 and summarized graphically in Figure 5. Altho the three curves of Figure 5 do not coincide they have the same general trend. The discrepancy between the May-11 plantings for 1926 and 1927 was perhaps due to an accidental warm period in the storage during late April, 1927. The 1926 curve, therefore, probably represents more accurately the normal sprouting during May. If the 1927 curve be thus corrected, the grand average of the three seasons shows the following: (1) The rest period terminated in December. (2) The single-sprout stage extended until early March. (3) From 56-gram seed pieces there was an average of two sprouts in plantings about May 1, three sprouts in plantings about June 1, and four sprouts about July 1.

OTHER FACTORS AFFECTING THE CHARACTER OF SPROUTING

STORAGE TEMPERATURE

It is not uncommon to store seed potatoes at a temperature near freezing, even tho it has been demonstrated (12) that the accumulation of sugar in a tuber held below 3° C. is associated with an increase in respiration, which may mean an unnecessary loss during storage. During the winter of 1924-25 a small pile of seed potatoes protected by alternate layers of straw and soil was held between 0° and 1° C. from the middle of December until the first of May. This method of covering potatoes in the field is called in Ohio "pitting". The temperature in the experimental lot was read

at weekly intervals by means of a resistance thermometer. During the following three seasons, a similar temperature was obtained in a commercial cold storage. The seed held at this low temperature was compared for number of sprouts with that held near 3° in the barn basement. The results are given in Table 5. The tubers were kept practically dormant in the barn basement, and com-

TABLE 5.—Comparative Sprouting of Seed Potatoes From Cold Storage and Basement Storage

Average number of sprouts from 56-gram pieces planted in the field

Date planted	Cold or pit storage 0° to 1°C	Basement storage 3° to 5°C	Difference due to storage temperature
May 6, 1924	1.44	1.68	0.22
May 11, 1925	1.97	2.31	.34
June 28, 1926	2.41	3.06	.65
April 11, 1927	1.68	1.94	.26
May 24, 1928	1.71	2.41	.70

pletely dormant in the cold storage. In the comparative field plantings the cold-stored seed produced fewer sprouts than the basement samples. The later the planting, the greater the difference. The cold storage (near 0° C.) evidently retarded the physiological processes which lead to an increase in multiple sprouting.

Fig. 6.—Differences in multiple sprouting in field plantings of late May, late June and early August

Warm storage and desprouting.—After the termination of the rest, if the storage temperature is above 5° C., the buds on a potato tuber start to grow. The number of buds which develop in

a warm storage is the same as if the tubers had been planted whole in warm soil. In a warm room, then, terminal buds sprout as soon as the rest period is ended. If such tubers are planted whole without injury to the sprouts, the terminal sprout continues development. But if it is injured or broken off, as frequently happens, two or more secondary sprouts appear. By repeated desprouting, Appleman (3) found continued increase in the number of sprouts. How much of this increase in multiple sprouting was directly due to the desprouting and how much to the prolonged warm storage was not determined. In practice this question is of little or no importance, for it is impossible to plant potatoes that have sprouted in a warm dark storage without injury to the sprouts

In preliminary experimental comparisons during 1924, a sample stored in a dark laboratory closet from January until May, desprouted three times during this period, produced an average of 2.58 sprouts per piece when cut and planted in the field, while dormant tubers averaged 2.00 sprouts.

Greater extremes in temperature were sought in 1926. Two lots were stored in a dark box in a warm greenhouse. One lot stored thruout March and April in this box and desprouted three times during the two months, produced 3.58 sprouts per cut piece when planted May 4; the other lot stored for but one month in the box and desprouted once, produced 3.44. The seed tubers held dormant averaged 1.82 sprouts at this planting. Warm, dark storage for one month with one desprouting thus about doubled the number of sprouts, and an extra month of warm storage gave practically no additional effect.

As a whole these data show that the higher the storage temperature, the larger the number of buds developing into sprouts when the tubers were cut and planted.

STORAGE VENTILATION

Incidental observations in 1924 on the sprouting of potatoes taken from the surface and from the interior of a storage pile disclosed no marked differences that might be attributed to the difference in ventilation. These observations were supported by the fact that the sprouting of the tubers from an unventilated pit one year was essentially the same as from a better ventilated cold storage the succeeding years.

To obtain more exact data on the effect of moisture and carbon dioxide, four metal cans, each with tight fitting friction lid and

holding about 10 kilograms of potatoes, were filled with seed tubers in November 1925. In one can space was left for a dish of calcium chloride to absorb moisture, in another soda lime was used to absorb carbon dioxide, and in a third both calcium chloride and soda lime were added. A small hole, less than 1 millimeter in diameter, was punched thru the lid of each can so that the pressure inside would be maintained at that of the atmosphere.

The cans were stored unopened in the barn basement until April 20. At this time the tubers in the cans containing calcium chloride were dry but not shriveled. The cans without the drier were wet and had the characteristic moldy odor of a damp potato storage. The tubers were immediately cut and planted in the field. The characteristic development in the field was two sturdy sprouts per hill on all of the plantings. The exact counts at harvest are given in Table 6. The differences disclosed by the counts are small. The removal of either moisture or carbon dioxide appears to have slightly reduced the number of sprouts, but when both were removed there was clearly no significant effect in comparison with the unventilated treatment.

TABLE 6.—Effect on Sprouting of Removal of Moisture and Carbon Dioxide During Storage

Average number of sprouts, from 56-gram pieces planted April 20, 1926

Storage treatment, from November to April 20	Sprouts per piece
In unventilated can	2.23
Moisture removed with calcium chloride	2.03
Carbon dioxide removed with soda-lime	2.13
Both moisture and carbon dioxide removed	2.27

More severe desiccation was obtained in a supplementary experiment in 1928 by spreading tubers in a warm, dry room for ten days prior to planting. This treatment produced perceptible wilting, and the seed pieces averaged 1.61 sprouts in four replicated plantings. The check lot from humid storage averaged but 1.41 sprouts per piece.

The difference in the two experiments is probably attributable to the difference in degree of desiccation. After the treatment of 1926 the tubers were dry but firm, and they sprouted the same as damp tubers; in 1928 the tubers were wilted and gave a small increase in number of sprouts. When compared with storage temperature or length of storage, these results from ventilation are relatively unimportant.

EXPOSURE TO LIGHT

Potatoes held in a warm dark storage shrivel and produce long fragile sprouts. Tubers spread out in a warm light place become heavily suberized, green, and produce short, tough sprouts that adhere during the processes of planting. Exposing seed potatoes to light is thus resorted to as a means of keeping them in good condition when it is impractical to keep them from sprouting in a dark storage. It is also occasionally adopted as a means of hastening growth of early varieties.

Greening compared with dormant storage.—Rosa (14) greened several lots of early varieties for about ten days prior to planting with variable results as far as the number of sprouts was concerned. His data as given in Table 7 included nine comparisons of which five showed an increase and four a decrease in average number of sprouts from exposure to light.

TABLE 7.—Effect of Greening Prior to Planting on the Number of Sprouts

Data from Rosa (14). Tubers cut to approximately 1 ounce pieces

Variety	Dormant	Greened
Irish Cobbler, Northern grown	2.10	2.67
Missouri spring crop	3.44	2.80
Missouri fall crop	1.43	1.80
Early Ohio, Northern grown	1.63	2.00
Missouri spring crop	3.96	3.20
Missouri fall crop	1.37	1.57
Rural New Yorker, Northern grown	2.25	2.12
Missouri spring crop	2.42	2.90
Missouri fall crop	1.93	1.48

In the present study, which was confined to the Russet Rural variety, tubers were exposed to light for four weeks either in the greenhouse or outside, with likewise variable results; but in all cases there was some increase in number of sprouts due to the greening (Table 8). The variation in the results suggests that some other factor was more important than the exposure to light.

TABLE 8.—Comparative Sprouting of Greened and Dormant Tubers

Average number of sprouts per piece in field plantings from tubers greened one month and from tubers held dormant in cool basement

Date planted	Dormant	Greened
May 11, 1925	2.31	2.44
May 4, 1926	1.82	2.19
June 1, 1926	2.10	3.15
June 28, 1926	3.06	3.08

During long exposure to light in a greenhouse there is gradual increase in multiple sprouting exactly analogous to changes in tubers in cool storage. The data of Table 9 illustrate this. Results from the three samples placed out to green at different dates show not only an increase in degree of multiple sprouting at successive plantings but also that on any given planting date the sprouting of the three samples was practically identical. On June 28, for instance, tubers greened for 16 weeks, beginning March 8, produced almost exactly the same number of sprouts as those greened since May 3, only 8 weeks. In this experiment, therefore, the length of time the tubers were exposed to light was a negligible factor in the character of sprouting.

TABLE 9.—Effect of Length of Period of Greening on Sprouting

Average number of sprouts per piece in field plantings from tubers exposed to light in a greenhouse for various periods

Date planted	Beginning of period of greening		
	March 8	April 5	May 3
	Sprouts	*Sprouts*	*Sprouts*
May 4	2.30	2.69	.....
June 1	3.23	3.49	3.15
June 28	4.00	3.78	4.03

Further evidence confirming this conclusion was obtained from small whole tubers exposed to light in a greenhouse thru practically the entire storage period. After prolonged exposure the sprouting was essentially the same as that of similar tubers greened for four weeks prior to planting. The tubers were planted whole April 11, 1927, and gave sprout counts as follows:

Greened about 6 months	2.62 sprouts
Greened 4 weeks	2.68 sprouts
Not greened	1.94 sprouts

Greening compared with desprouting.—Since it was found in the temperature studies that warm storage followed by desprouting resulted in a much larger number of sprouts than cool storage, it might be inferred that warm storage would result in more sprouts than greening at the same temperature. This inference was verified by storing tubers in a dark box adjacent to those being greened in the greenhouse. The aim was to give the same temperature to the darkened as to the lighted tubers, altho in this respect the conditions were only approximations. Lots were placed under these conditions at intervals of four weeks beginning

March 8, and then planted in the field at similar intervals beginning May 4. The average number of sprouts from 56-gram pieces are given in Table 10. In all comparisons the desprouted tubers from the dark box produced more sprouts than the greened seed, indicating that at this greenhouse temperature, exposure to light retarded the physiological changes which lead to an increase in multiple sprouting.

TABLE 10.—Comparative Sprouting of Greened and Desprouted Tubers

Average number of sprouts per piece in field plantings from greened tubers and from tubers stored in the dark at approximately the same temperature, desprouted prior to planting

Date planted	Period of treatment, weeks	Greened	Desprouted
May 4, 1926	4	2.69	3.44
	8	2.30	3.58
June 1, 1926	4	3.15	3.51
	8	3.49	3.82
	12	3.23	4.17
June 28, 1926	4	3.08	4.11
	8	4.03	4.94

Comparisons of more practical interest were made between greened tubers and those sprouting slightly in a basement storage. The basement was held as cool as possible during the spring and represented a good farm storage where due attention is given temperature control by means of ventilation. The average length of the sprouts removed prior to planting together with the average number of sprouts obtained in the field are given in Table 11. The differences were so small as to be of doubtful significance. The practical conclusion, judging by the sprouting habit, is that there is no advantage in greening over holding tubers in a storage in which there is but little sprouting.

To summarize these studies of greening: (1) Tubers from an ordinary dark cool storage did not differ significantly in sprouting

TABLE 11.—Comparison of Greened Tubers With Sprouted Tubers From Basement Storage

Average number of sprouts per 56-gram piece. Tubers from the basement desprouted prior to cutting

Date planted	Length of sprouts removed, inches	Number of sprouts	
		Greened seed	Desprouted seed
June 14, 1924	4	2.45	2.16
May 24, 1927	1	2.51	2.41
June 15, 1927	6	2.54	2.52

habit from tubers that had been exposed to light in a warm place for a period prior to planting; (2) Tubers that produced long sprouts in a warm dark storage, and were desprouted prior to planting, had more sprouts than tubers that had been exposed to light prior to planting.

MATURITY THE PRECEDING SEASON

In the literature dealing with the relative value of mature and immature seed potatoes the term "immature" is applied in some instances to potatoes planted at the usual time but dug before the end of the growing season; and in other instances, to late plantings that were immature at the close of the growing season. In considering the character of sprouting this distinction is important. To avoid confusion, therefore, the following experiments are termed studies of time-of-digging and time-of-planting rather than studies of maturity.

Time of digging.—During 1925, samples were dug at 15-day intervals beginning July 15 from an early planting made April 13. At the first digging the largest tubers weighed less than 50 grams; not until the August 15 harvest were the tubers large enough to give an adequate supply of suitable seed pieces. The samples were placed in cold storage as soon as dug. In early November 12 tubers from each sample were placed in damp spaghum in a laboratory and examined at weekly intervals for evidence of sprouting. The results of three of these observations are given in Table 12 in terms of the average number of sprouts per tuber. The following spring, three field plantings were made from the samples dug August 15 and later. The sprouts per piece in these plantings are also reported in Table 12.

TABLE 12.—Effect of Time of Digging on Sprouting the Following Season

Average number of sprouts from whole tubers in a laboratory during winter, and from cut pieces weighing 40 to 60 grams planted in the field the following spring

Date of digging	Date of laboratory examinations			Date of field plantings		
	Nov. 23	Dec. 22	Jan. 19	April 20	May 4	June 2
July 15	0.5	1.0	1.0	†	†	†
August 1	0.2	1.0	1.0	†	†	†
August 15	0.1	1.0	1.0	1.75	2.00	2.32
September 1	0.0	0.5	1.0	1.80	1.99	2.50
September 15	0.0	0.5	1.0	1.84	2.10	2.42
October 1*	0.0	0.0	1.0	1.90	1.89	2.41

*By October 1 the tops were dead.
†No field plantings made of the two most immature lots.

The early-dug tubers sprouted earlier in the laboratory than did the later samples[1], but in the field the number of sprouts was practically the same on the four samples tested. The usual precaution of weighing each seed piece was not followed in these plantings, and in view of this the small differences are not considered significant.

While this experiment was in progress the work of Appleman and Miller (4) was published in which they reported that normal maturation changes proceed in tubers dug immature, so that by the end of the rest period such tubers have essentially the same chemical composition as those allowed to mature on the plants. From their results it might be inferred that the sprouting of immature tubers would be the same as that of mature tubers. As this inference substantiated the preliminary data at hand the experiment was not carried further. The conclusion from the one season's data is that the time of digging has no important effect on the number of sprouts per piece the following spring.

Time of planting.—Plantings at intervals of about a month in both 1925 and 1926 were harvested after the tops of the early plantings had normally ripened and after the tops of the late plantings had been killed by frost. The tubers were stored in the barn basement.

TABLE 13.—Effect of Degree of Maturity, Due to Difference in Time of Planting, on Sprouting the Following Season

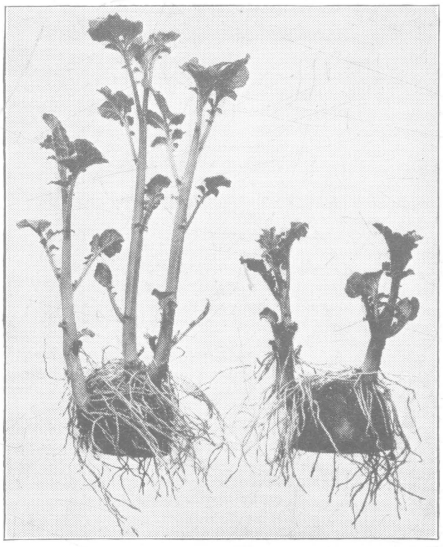
Average number of sprouts per 56-gram piece in field plantings. All pieces from apical end of tubers

Date planted to obtain different degrees of maturity	Conditions at close of growing season	Date of planting the following season and sprout counts		
		April 21	June 2	June 28
April 13, 1925	Mature	1.90	3.64	4.14
May 28	Mature	1.68	3.16	4.08
June 30	Immature	1.41	2.82	3.50
		April 12	May 24	
April 20, 1926	Mature	1.95	3.07	
May 20	Mature	1.87	2.94	
June 21	Immature	1.61	2.52	

A few tubers from each of the 1925 plantings were planted in pots in the laboratory to determine the end of the resting stage. The tubers from the planting of April 13 were sprouting when examined January 2. Those from the late planting, June 30, were first sprouting on January 18.

[1]Rosa recently reported considerable data showing diametrically opposite results; his later-dug samples sprouted earlier (Cal. Exp. Sta. Hilgardia 3:99-124. 1928).

The sprout counts from plantings in the field are given in Table 13. The mature tubers in all instances produced more sprouts than the immature ones. The characteristic differences are well illustrated in Figure 7. The results as a whole disclose a shift in the annual vegetative cycle. The mature tubers entered the resting stage earlier and emerged earlier than the immature lots. Likewise any given stage of multiple sprouting in the mature lots was two to four weeks earlier than in the immature lots. For example, the most mature lot planted June 2, 1926 gave essentially the same type of sprouting as the immature lot planted June 28. This shift in the annual cycle, however, did not correspond directly to the difference in date of planting; a difference of two months in the date of planting shifted the cycle of the following spring but two to four weeks.



Mature Immature

Fig. 7.—Characteristic difference in sprouting from mature and immature tubers planted in May

Rosa (14) reported similar results with other varieties (Table 14). He used seed tubers from a spring crop planted the last of March and from a fall crop planted about July 1. With these extremes in time of planting he obtained greater differences in number of sprouts than were obtained in the present study with the Russet Rural. In every instance seed from the early spring crop produced more sprouts than fall-crop seed.

TABLE 14.—Comparison of Sprouting From Spring-Crop and Fall-Crop Tubers

Average number of sprouts in spring plantings. Seed pieces weighing approximately 1 ounce. Data from Rosa (14)

Variety	Spring crop tubers	Fall crop tubers
Irish Cobbler	3.44	1.43
Early Ohio	3.96	1.37
Bliss Triumph	3.20	2.32
Rural New Yorker	2.42	1.93

In view of the present importance of virus diseases it should be added parenthetically that special precautions were taken to procure high quality certified seed for the plantings at Wooster, and that no symptoms of virus disease were detected in the plants of these maturity experiments.

SIZE OF SEED PIECE

It has been repeatedly demonstrated in field experiments that the number of sprouts that develop on a seed piece is a direct function of the weight of the piece (Arthur 5, Rosa 14, Stuart *et al.* 16). Such a wide range of conditions is covered in these experiments that the generalization may be said to hold for all degrees of multiple sprouting.

TABLE 15.—Effect of Weight of Seed Piece on the Number of Sprouts per Piece Planted at Different Dates

Tubers from cold storage

Weight of piece, grams	Date planted	
	April 20, 1926	June 1, 1926
14	1.12	1.24
28	1.30	1.62
56	1.80	2.28
	April 12, 1927	May 23, 1927
5	1.0	....
10	1.0	.....
15	1.0	1.24
25	1.17	1.52
35	1.61	1.87
50	1.90	2.25
75	... .	3.10

Studies on weight of seed piece during 1926 and 1927 agreed with the results reported in the literature; in all plantings the larger the seed piece, the greater the average number of sprouts. The data given in Table 15 show a similar increase in number of sprouts in both seasons. When graphed as in Figure 8 the data further show that an increase of 10 grams in weight of the piece resulted in an average increase of .18 to .28 sprout per seed piece.

Some of the data of Stuart *et al.* (16) with the Irish Cobbler admit of similar plotting. The result discloses a higher degree of multiple sprouting and a more rapid increase in number of sprouts than was obtained here with the Russet Rural, especially in late plantings. Their plantings in Virginia about March 1 gave an

increase of .23 sprout for each 10-gram increment in the seed piece; but plantings in Maine about May 20 gave an increase of .41 sprout for each 10-gram increment.

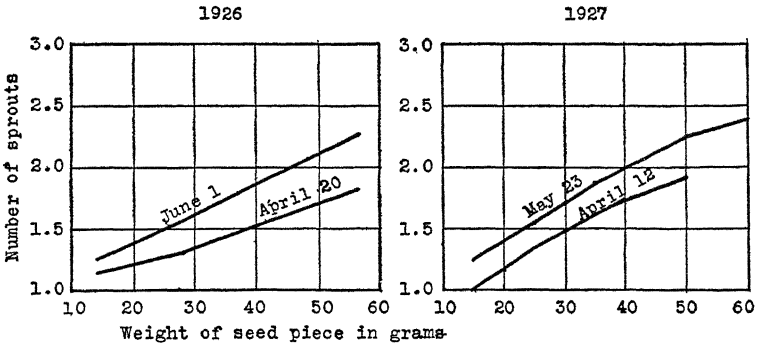


Fig. 8.—Effect of weight of seed piece on number of sprouts in early and late plantings

Referring again to Figure 8, it may be noted that the curves of the later plantings are steeper than these of the early plantings. In other words, at the later dates, when the tubers showed a correspondingly higher degree of multiple sprouting, there was greater increase in the number of sprouts from a given increment in the weight of the seed piece than at the earlier dates. This correlation between degree of multiple sprouting, as indicated by the number of sprouts on 30-gram pieces, and the increase in number of sprouts due to 10-gram increments in the seed is illustrated by arranging the data as in Table 16.

TABLE 16.—Relation of Degree of Multiple Sprouting to the Increase in Number of Sprouts With Increased Weight of Seed Piece

Variety	Planted	Average number of sprouts on 30-gram piece	Increase in sprouts with 10-gram increment in seed pieces†
Russet Rural	April 20, 1926	1.3	0.18
Russet Rural	April 12, 1927	1.5	.24
Russet Rural	June 1, 1926	1.6	.25
Russet Rural	May 23, 1927	1.7	.28
Irish Cobbler*	About March 1	1.9	.23
Irish Cobbler*	About May 20	2.6	.41

*Calculated from data of Stuart and coworkers (16).
†Approximate average values obtained by smoothing the curves of Figure 8 to straight lines, and similarly treating the data of Stuart and coworkers.

Further mathematical relations might be deduced, but, in view of the limited data at hand, such calculations seem hardly justified. The important point is simply that the effect of the weight of seed piece varies directly with the stage of multiple sprouting of the tubers.

SOIL TEMPERATURE

Altho differences in type of sprouting are here attributed to internal changes in the tubers, the fact that the degree of multiple sprouting increases during a period when the average soil temperature in the field is also increasing cannot be overlooked. The possibility that the soil temperature might affect the number of sprouts was tested in two experiments. The first was a comparison of the sprouting outside in cold soil during April (temperature about 10° C.) with that in a warm greenhouse where the average temperature of the soil was above 20° C. Outside, 60 percent of the pieces produced but one sprout, the balance two. In the greenhouse exactly half of the pieces produced one sprout. The difference was too small to be of any real significance.

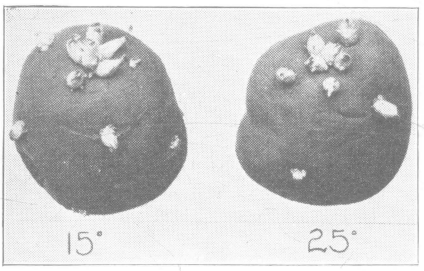


Fig. 9.—Similarity of sprouting at 15° and 25° C. in July

In the second experiment, whole tubers were planted in sand in incubators at 15° C. and at 25° C. in July 1927. Sprouts developed on all of the eyes at both temperatures as shown in Figure 9. Accurate comparative counts were precluded by partial rotting of the tubers at the higher temperature, but in both incubators the sprouting was typical of that observed in the field in late July plantings.

These results agreed with field observations. No variation in number of sprouts was noted that could be attributed to the soil temperature, except in those cases where rotting ensued. It should be added that soil temperature and soil moisture have a marked effect on the rate of growth of potato sprouts, so much so in fact that attempts to determine the effect of storage on the vigor of sprouts at successive field plantings were quite unsatisfactory. The present study was therefore confined to the number of sprouts, which appears to be independent of ordinary fluctuations of soil temperature and moisture.

CHEMICAL TREATMENTS

In his classical study of the rest period and its termination, Appleman (1) found that peeling tubers or treating them with ethyl bromide broke the rest and induced several sprouts to grow.

One of his photographs shows two tubers with two and three sprouts, respectively, as a result of 30 minutes treatment with ethyl bromide gas before plantng; two similar tubers treated but 15 minutes produced one and no sprout, respectively. The longer treatment then induced multiple sprouting.

Denny (11) recently obtained similar results using solutions of thiourea. His photographs show that treatment with a 4-percent solution induced the development of more buds per seed piece than a 2-percent solution.

The writer repeated some of Denny's experiments soaking cut pieces in different concentrations of thiourea for various periods. The most interesting results were obtained with 1-percent solutions, a concentration which gave the minimum of seed piece rotting. On 50-gram pieces treated January 3, 1927, then planted in the greenhouse, the average number of sprouts were as follows:

Hours of soaking	Sprouts
0	1.0
1	2.0
2	2.3
12	5.0
36	6.0 some injury

Typical specimens are shown in Figure 10. The same type of sprouting was obtained in January by one hour treatment with thiourea as occurs normally in early May, and with the 12-hour treatment the sprouting was characteristic of that of July.

Untreated 1 hour 12 hours

Fig. 10.—Results from soaking seed pieces in thiourea solution for different periods

DISCUSSION

Taken as a whole, these studies show that potato tubers gradually lose apical bud dominance during the latter half of the storage period, with a resulting increase in degree of multiple sprouting. This change, due to undetermined physiological causes, proceeds slowly and regularly, and is only retarded or accelerated to a limited degree by varying external conditions. None of the treatments studied completely inhibited the change, and only by chemical treatment was it markedly accelerated.

Altho this study was confined to the Russet Rural variety various degrees of multiple sprouting have been reported for other varieties, so that it seems highly probable that a loss of apical dominance during the latter half of the normal storage period is characteristic of all varieties of the species.

Failure to appreciate the changes in character of sprouting has resulted in unexplained contradictory conclusions in many lines of field experiments with potatoes. As an example, the results from the use of mature and immature seed tubers may be cited. This literature, recently reviewed by Stuart, Edmonson, Lombard, and Dewey (17) shows striking contradictions. With attention focused on yield of tubers, little or no consideration being given to the spacing of the hills or to the fertility of the soil, it is not surprising that in some cases the immature seed with its fewer sprouts gave better results than mature seed, while in other instances the results were reversed. Analogous experiments with number of stalks of corn per hill conducted in various localities show similar conflicting results, but with corn the spacing of hills, the fertility of the soil, and the character of the climate have been duly considered and the results explained accordingly. With potatoes, similar explanations would seem to apply.

Conflicting conclusions are likewise to be found in the literature on size of seed piece. Due regard has not been given to the number of sprouts nor to the distance between hills. In this connection the present studies favor small pieces. The data of Table 15 show that the largest number of sprouts from a given quantity of seed tubers is obtained by cutting into small pieces. For example, two 25-gram pieces produce more sprouts than one 50-gram piece, irrespective of the date of planting. It is well known that it is possible to cut pieces so small that they cannot support vigorous sprouts, but it appears from the study of number

of sprouts that the economical and practical procedure is to cut seed into pieces as small as can be relied upon to produce vigorous sprouts, and then to adapt the spacing of the hills to this minimum size piece.

TABLE 17.—Estimate of the Average Number of Sprouts From Small Seed Pieces in Comparison With 56-gram Pieces

Date of planting	Sprouts from 56-gram pieces	Estimated number of sprouts	
		From 42-gram pieces	From 28-gram pieces
About May 1	2.0	1.7	1.4
About June 1	3.0	2.5	2.0
About July 1	4.0	3.4	2.7

At the outset of these experiments the practical economy of small seed pieces was not appreciated and relatively large pieces, 56 grams (2 oz.) each, were used, and having been adopted were continued thru the work. If these data are to be used to predict the number of sprouts in practical field culture, a correction based upon the weight of seed will be necessary. As an illustration, in Table 17 an estimate is made of the number of sprouts from 28-gram (1 oz.) and 42-gram (1½ oz.) pieces when 56-gram pieces are averaging 2, 3, and 4 sprouts. It should be added that the most economical weight of seed piece has not been determined at Wooster, but, judging from the literature and preliminary experiments, it is somewhere between 28 and 42 grams, hence the sprout estimates for these weights are given here.

SUMMARY

In field plantings of potatoes more than one sprout usually develops from each seed piece.

A study of the sprouting habit of the Russet Rural variety from successive plantings in the greenhouse and in the field disclosed the following stages: the rest period extended to December or early January; single sprouts were produced until March or early April; in succeeding plantings there was a progressive increase in the number of sprouts. From seed tubers stored near 4° C. cut into pieces weighing 56 grams and planted in the field there was an average of two sprouts per piece in plantings about May 1, three sprouts per piece in plantings about June 1, and four sprouts from plantings about July 1.

The average number of sprouts per cut piece was also influenced by (1) the maturity of the seed tubers, (2) the storage temperature and humidity, and (3) the weight of the cut piece. Mature tubers produced more sprouts than immature tubers when the difference in maturity was due to the time of planting the preceding season. Tubers stored at a temperature near 4° produced more sprouts than those stored near 0° C. Wilted tubers gave more sprouts than unwilted. The results from seed pieces of different weight agreed with the well-established fact that the number of sprouts is also a function of the size of the piece.

No significant differences in sprouting habit could be attributed (1) to the temperature of soil in which the seed was planted, nor (2) to differences in time of harvest from plantings made at the same date.

Thiourea treatment of seed pieces planted in January resulted in typical multiple sprouting such as is normal several months later.

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